National Aeronautics and Space Administration

Convection, thin cirrus, and dehydration in the tropical tropopause layer (TTL) observed by MLS and CALIPSO.

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August 20, 2007

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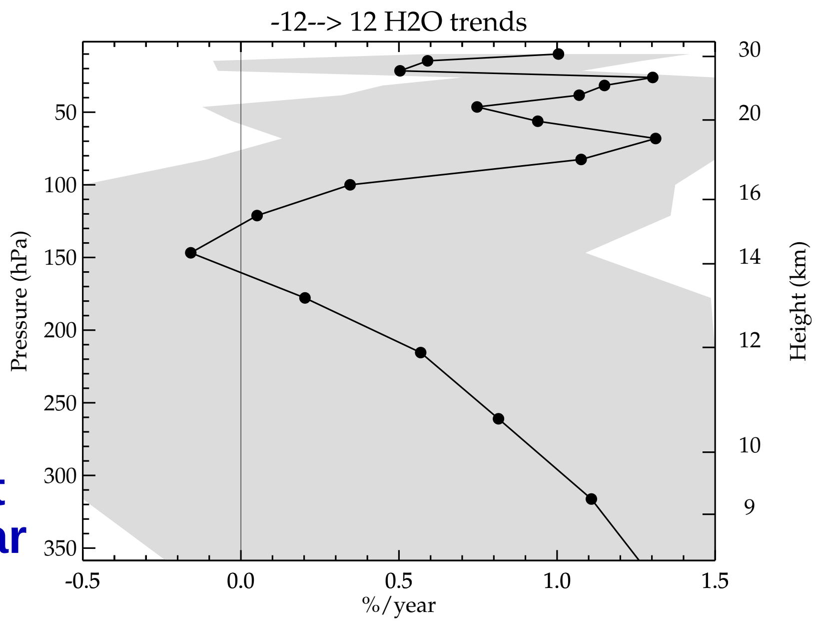
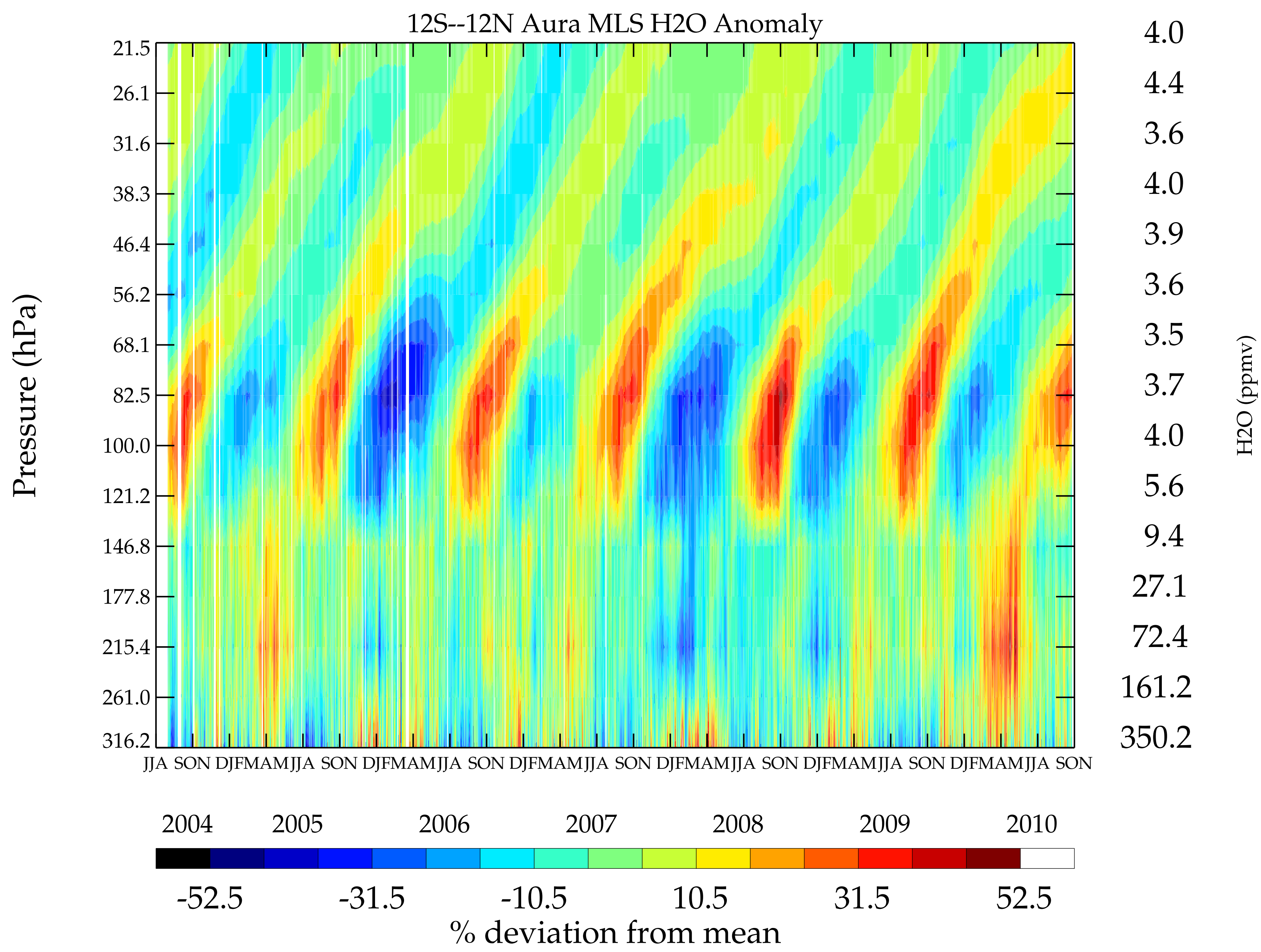
Introduction

- Understand the transport and dehydration of H_2O entering the stratosphere.
  - Solomon et al. (Science, 2010) show that statospheric H_2O has a significant impact upon global surface climate change. For example, assuming a 10% decrease in H_2O from 2000–2009 would reduce the rate of warming caused by increasing CO_2 and other greenhouse gases by 25%.
  - The long term statospheric H_2O behavior is partially understood in that interannual changes follow the same changes in tropical tropopause temperature but it is not clear that the multidecadal trend itself is following that of the tropical tropopause temperature.

- Additional considerations
  - Increases in anthropogenic aerosol pollution may alter the microphysics and warm the tropical tropopause.
  - Changes in convection.
  - Methane oxidation.
  - Changes in global circulation.
  - Accuracy of historic and current data sets. For example the 6-year MLS H_2O trend shows a slight increase.



MLS H_2O tape recorder.

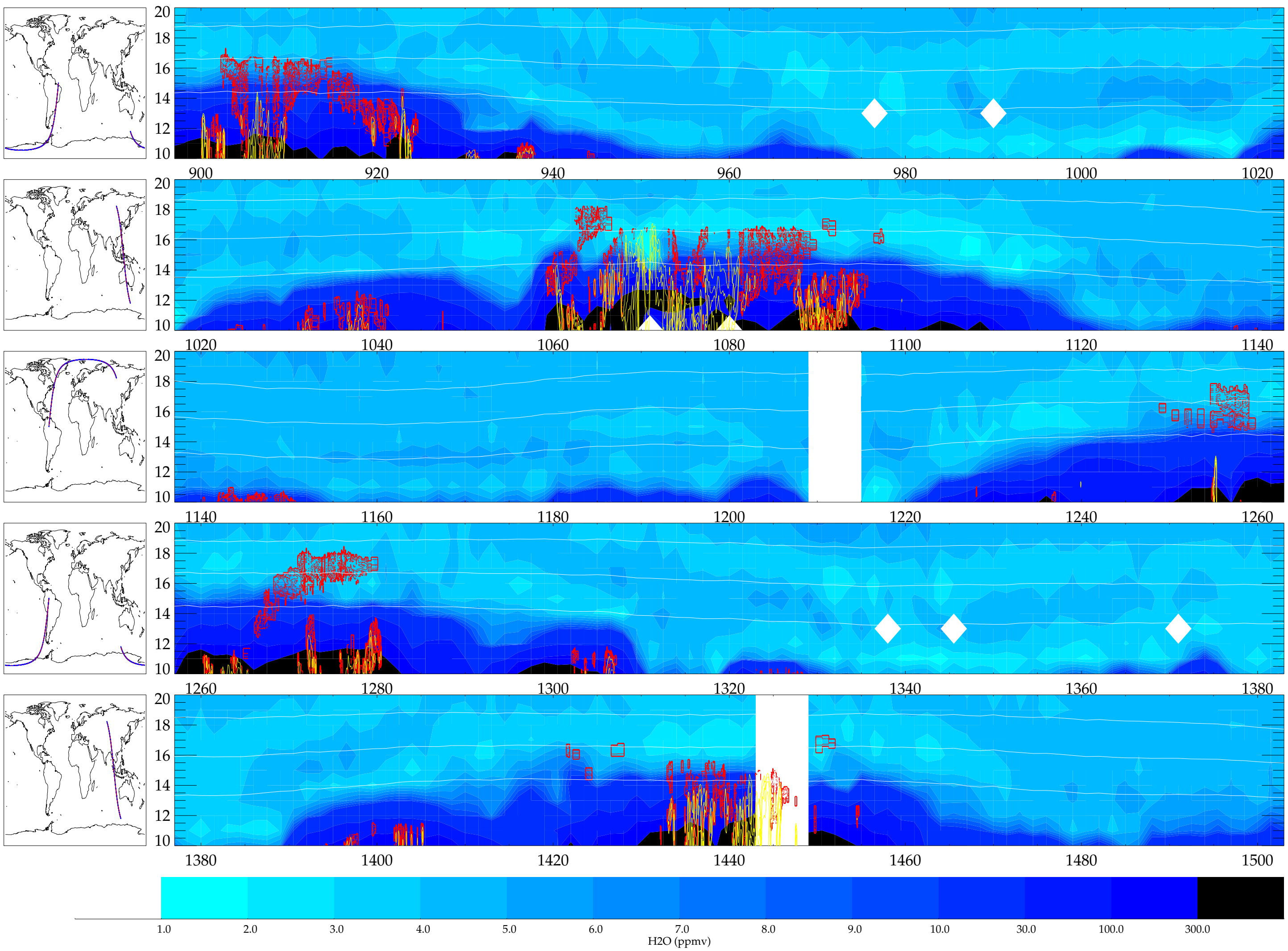


H_2O Investigation

- Find the cloud characteristics of H_2O in the TTL.
  - Since May 2008, the Aura satellite was repositioned in the A-Train so as to nearly align the MLS H_2O measurement footprint with the Ice Water Content (IWC) measurement track of CALIPSO and CloudSat.
  - Objective is to identify the conditions of dehydration in the TTL.
  - CALIOP cloud measurements and masks identify whether the MLS H_2O measurement occurs in convective, layered (isolated), or clear sky conditions.
- Aura MLS data.
  - MLS measures H_2O, O_3, HNO_3, CO, HCl, HCN, CH_3Cl(v3.3), CH_3CN(v3.3), and IWC.
  - Validation shows that MLS v2.2 H_2O is 10% accurate in the TTL (P $>$ 150 hPa
- CALIOP (and CloudSat) data.
  - CALIOP uses a 532/1064 nm LIDAR to measure atmospheric backscatter predominantly from clouds and aerosols. Backscatter is converted to IWC (v3.01) using an empirical relationship.
  - CALIOP v3.01 is a provisional product whose accuracy is not yet established.
  - CloudSat uses a 94 GHz RADAR to measure backscatter from clouds which is used to derive IWC. Data is used to identify convection.

MLS H_2O, CALIOP, and CloudSat IWC.

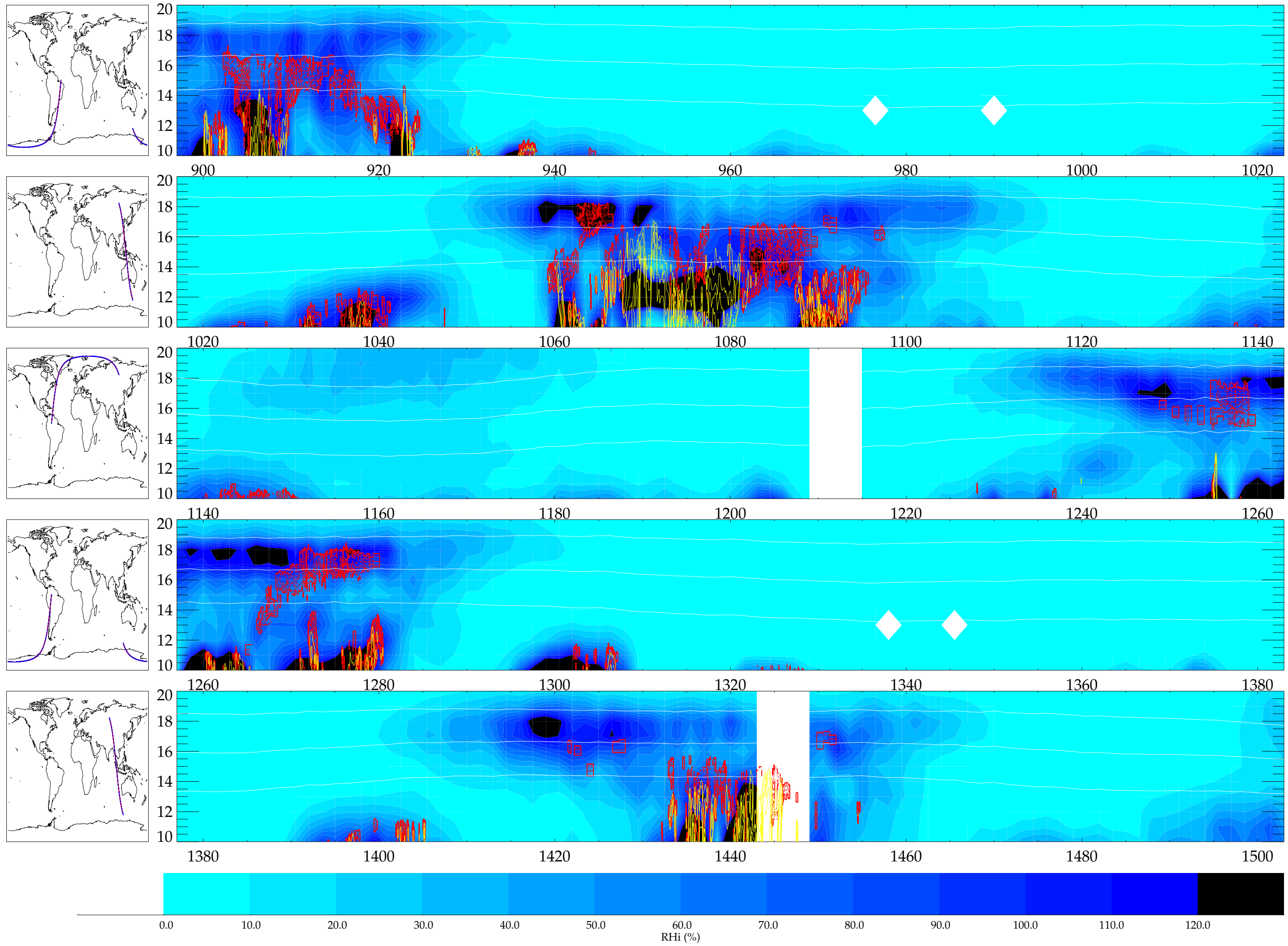
2 January 2009



Blue filled contours MLS v2.2 RHi (1–120%), red contours are CALIOP v3.01 IWC, (start at 0.001 mg/m^3), Yellow contours are CloudSat IWC, (start at 3 mg/m^3).

MLS RHi, CALIOP, and CloudSat IWC.

2 January 2009



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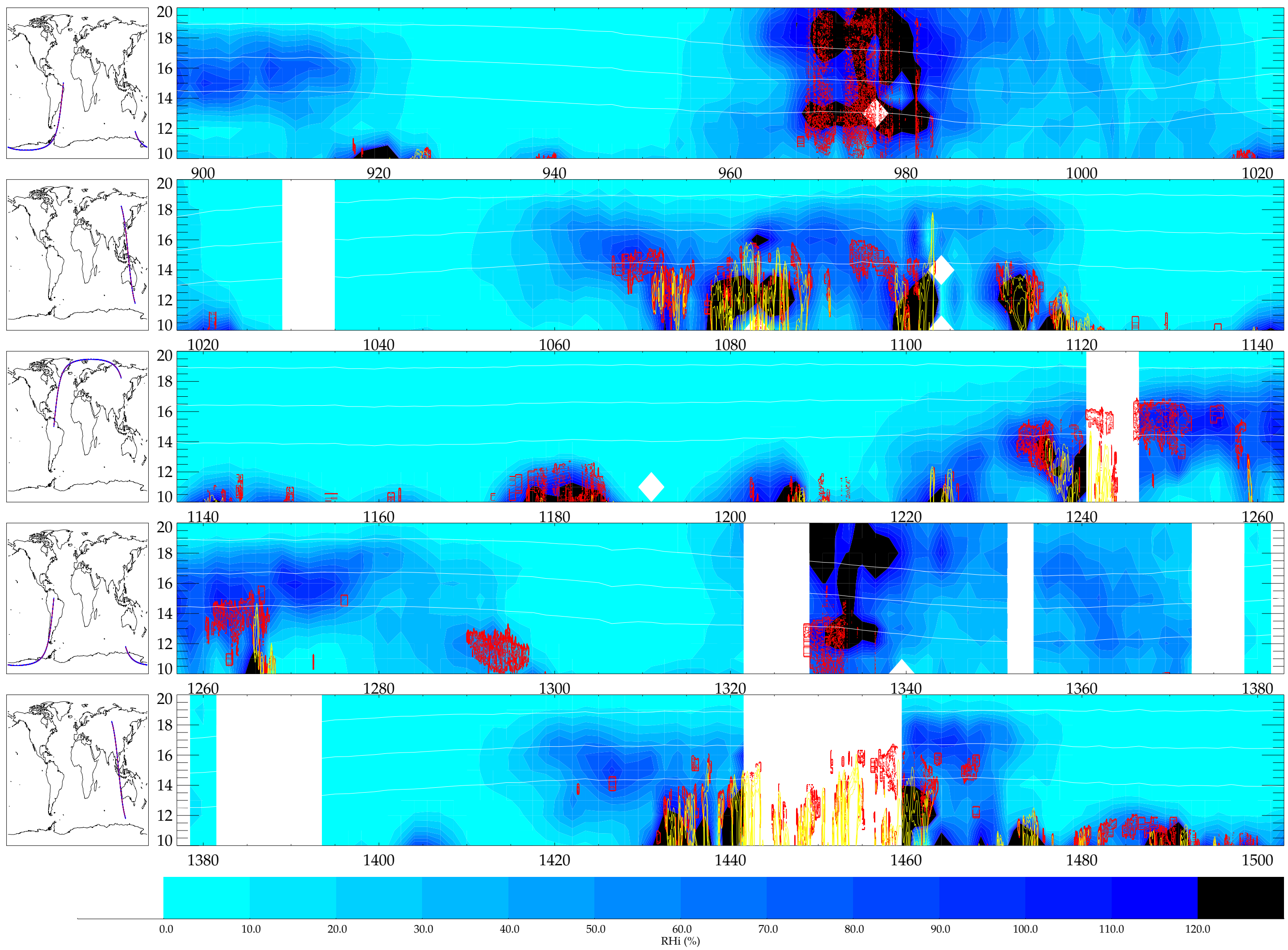
1 September 2008



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Classifying the Cloud State of MLS H_2O.

- Only consider clouds above 10 km.
- CALIOP IWC within $\pm$ 110 km (1°) of each MLS measurement is averaged. For each cloud layer in the average, the fraction of clouds and convective clouds based on the CALIOP cloud mask are computed.
- Convection:
  - CALIOP convective cloud mask fraction $>$ 0.
  - Any cloud having a vertical extent $>$ 4 km whose “bottom” is $<$ 12 km.
  - Special note is made when the averaged CloudSat IWC exceeds 2 mg/m^3.
- A layered Cloud is any non convective cloud with IWC $>$ 0.05 mg/m^3.
- Thin cirrus is a non convective cloud with 0.005 $<$ IWC $<$ 0.05 mg/m^3.
- Clear Sky are no clouds or clouds with IWC $<$ 0.005 mg/m^3.

Clouds and H_2O

❶ **Convection:**

- ➟ **A source of colder-than-environmental air which leads to in situ cloud formation and irreversible dehydration.**
- ➟ **A moistening agent by supplying H_2O and ice that can evaporate. when exposed to warmer environmental air.**
- ➟ **Direct dehydration by mixing in very dry cold air with little ice detrainment (Convective dehydration hypothesis Sherwood and Dessler 2001).**

❷ **Layered Clouds:**

- ➟ **In situ freeze-drying when moist air encounters a cold region.**
- ➟ **A moistening agent when sedimenting or advected clouds are exposed to warmer air.**
- ➟ **Left over cirrus from convection.**

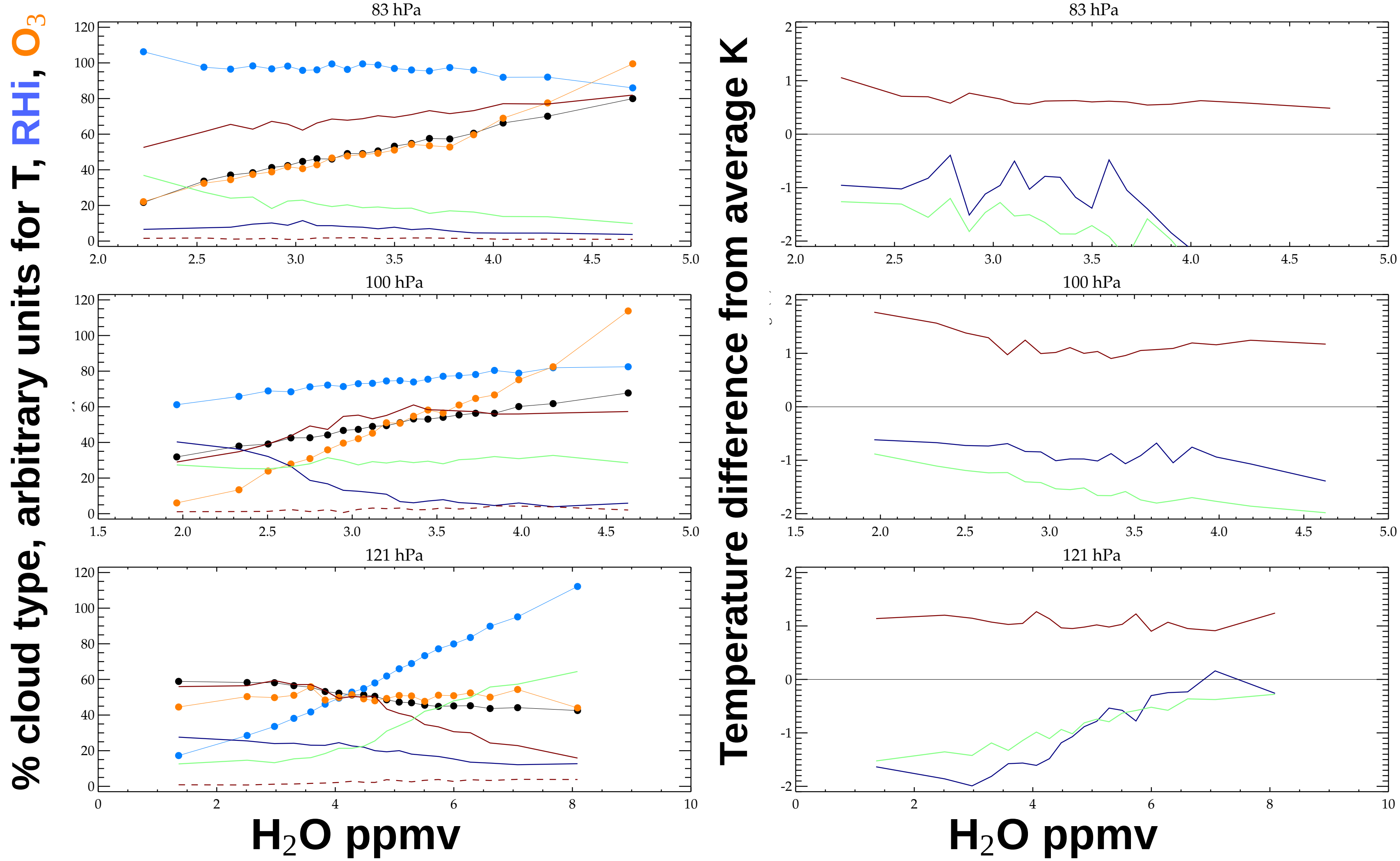
❸ **Thin layered clouds occur rarely, $<$ 3%.**

❹ **Clear Sky:**

- ➟ **Condensation/evaporation is not happening.**

H_2O amounts and Cloud Type

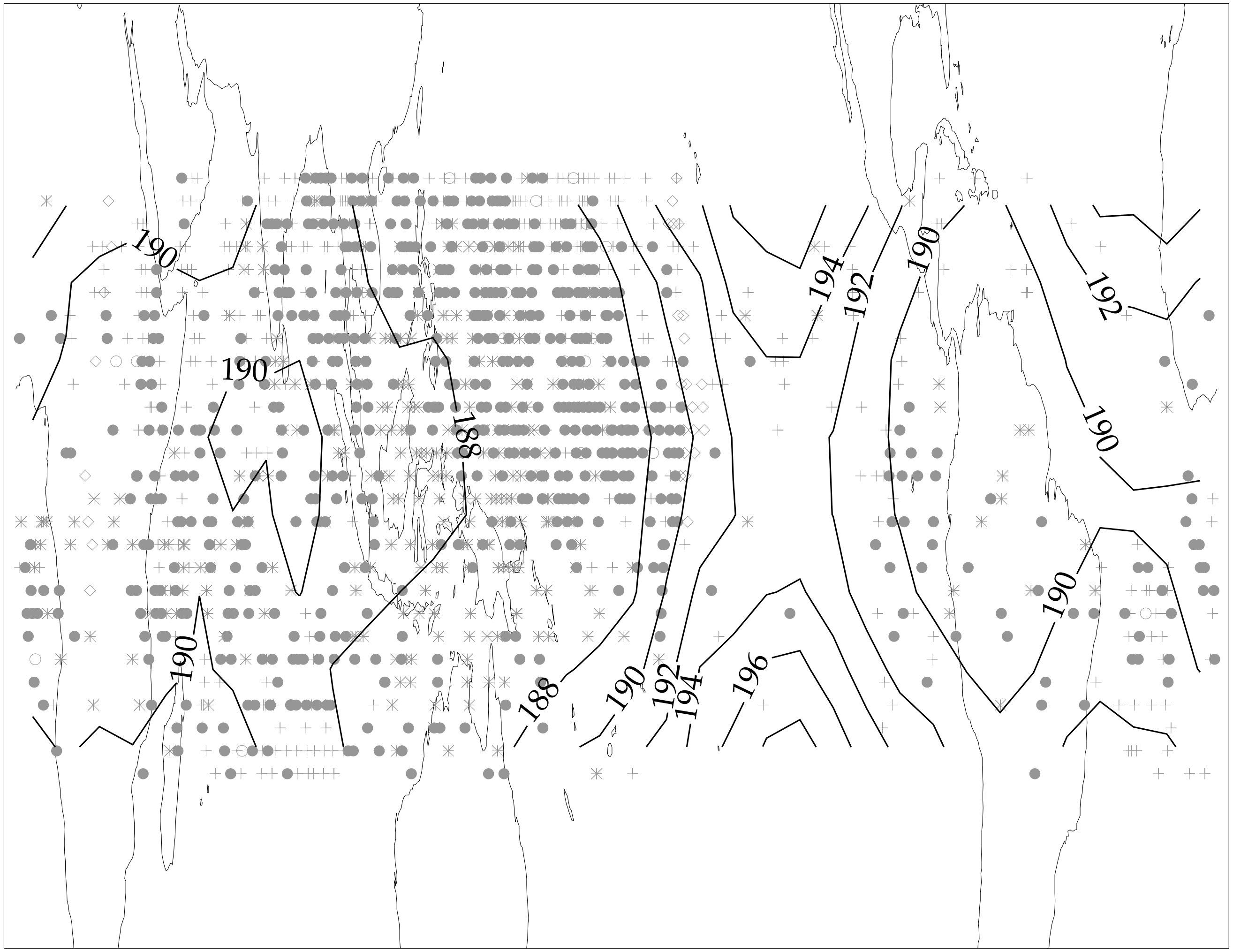
December–January 2008/2009



Clear sky: dark red, thin layer clouds: dark red dashed, layer clouds: green, convective clouds: dark blue, Temperature: black, O_3: orange, RHi: light blue.

Location of lowest 83 hPa H_2O

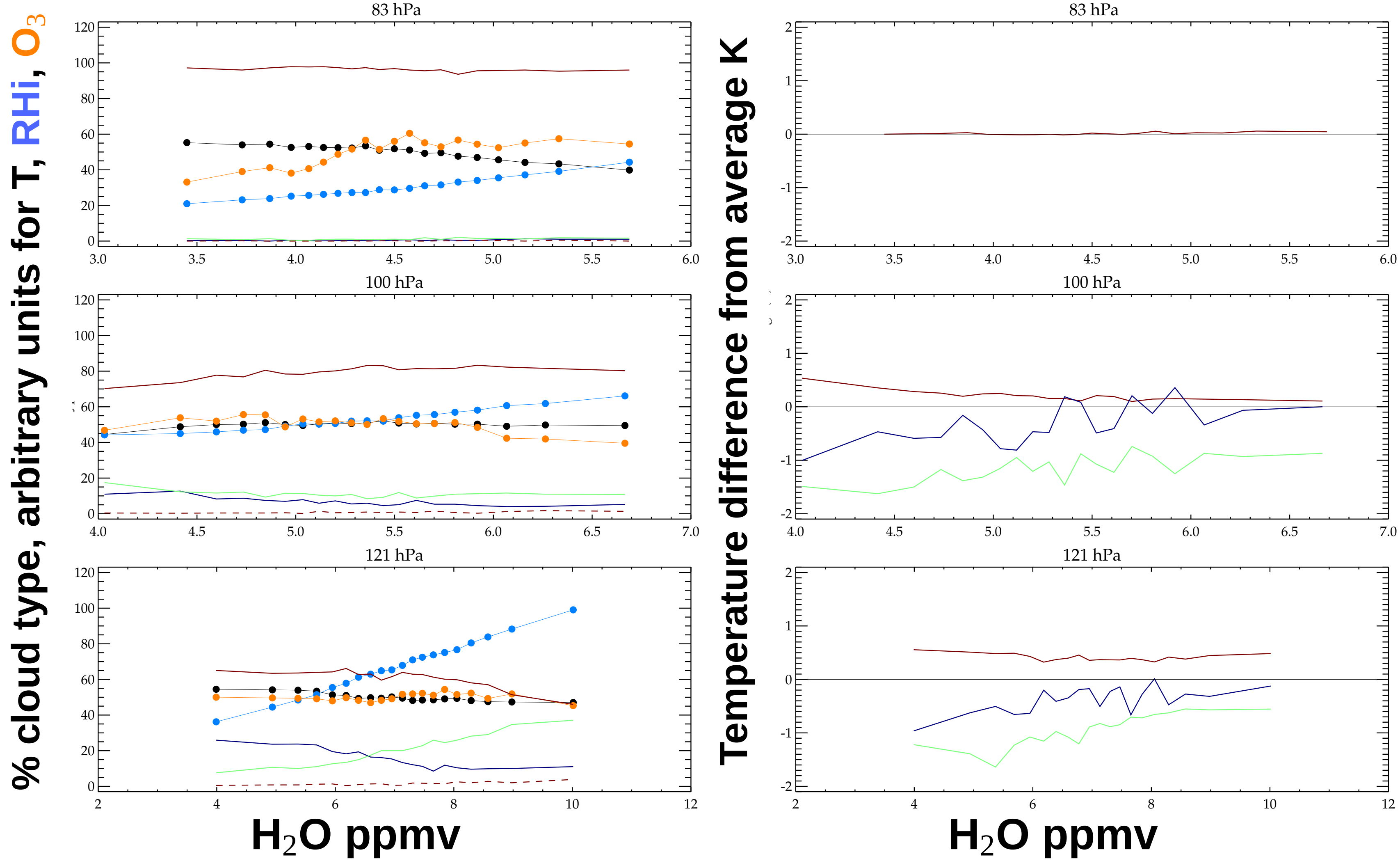
December–January 2008/2009



+ = clear sky, ⁎ = convection, • = layer cloud, ○ = thin layer, ◇ = unclassified

H_2O amounts and Cloud Type

August–September 2008



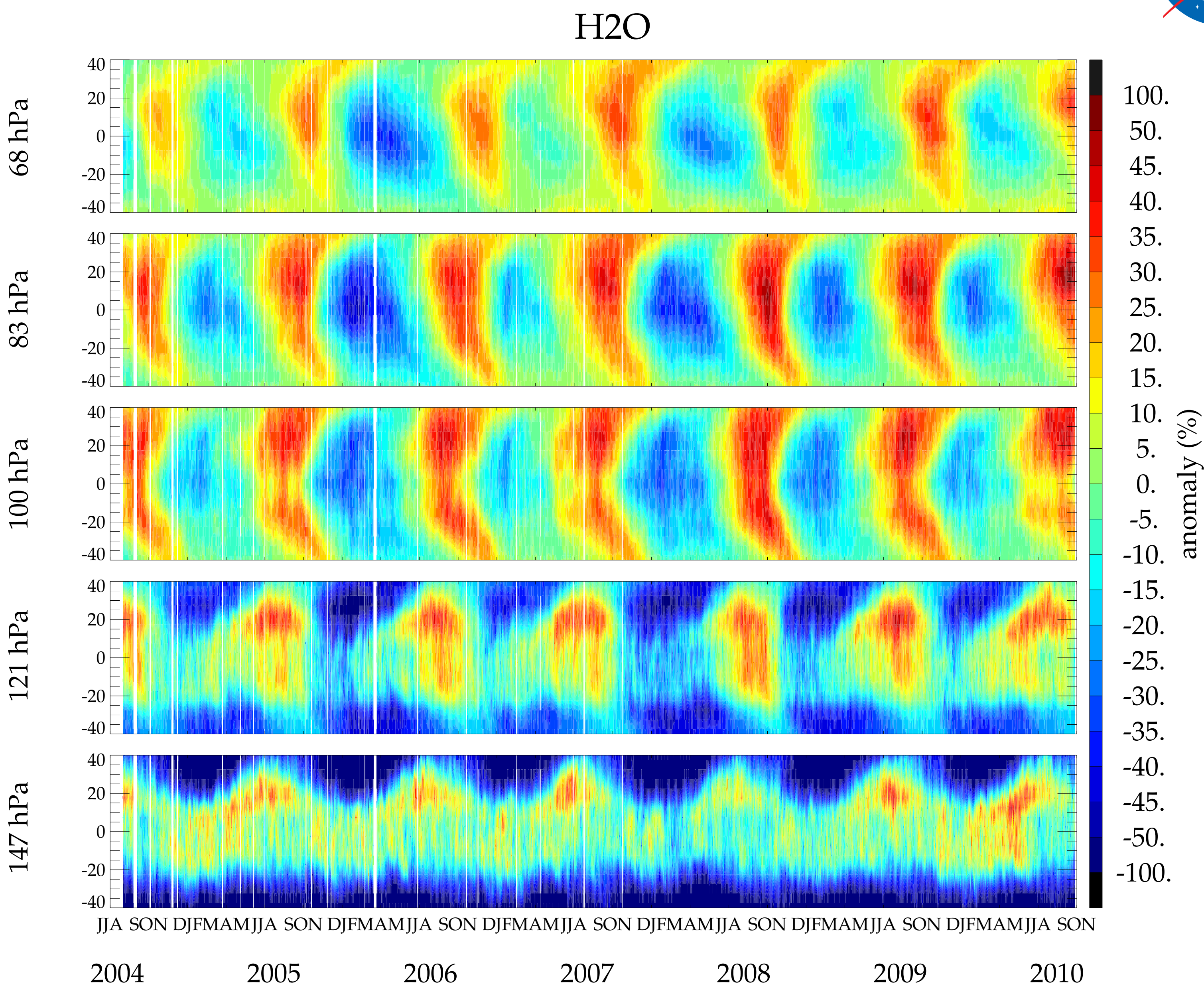
Clear sky: dark red, thin layer clouds: dark red dashed, layer clouds: green, convective clouds: dark blue, Temperature: black, O_3: orange, RHi: light blue.

Location of lowest 100 hPa H_2O

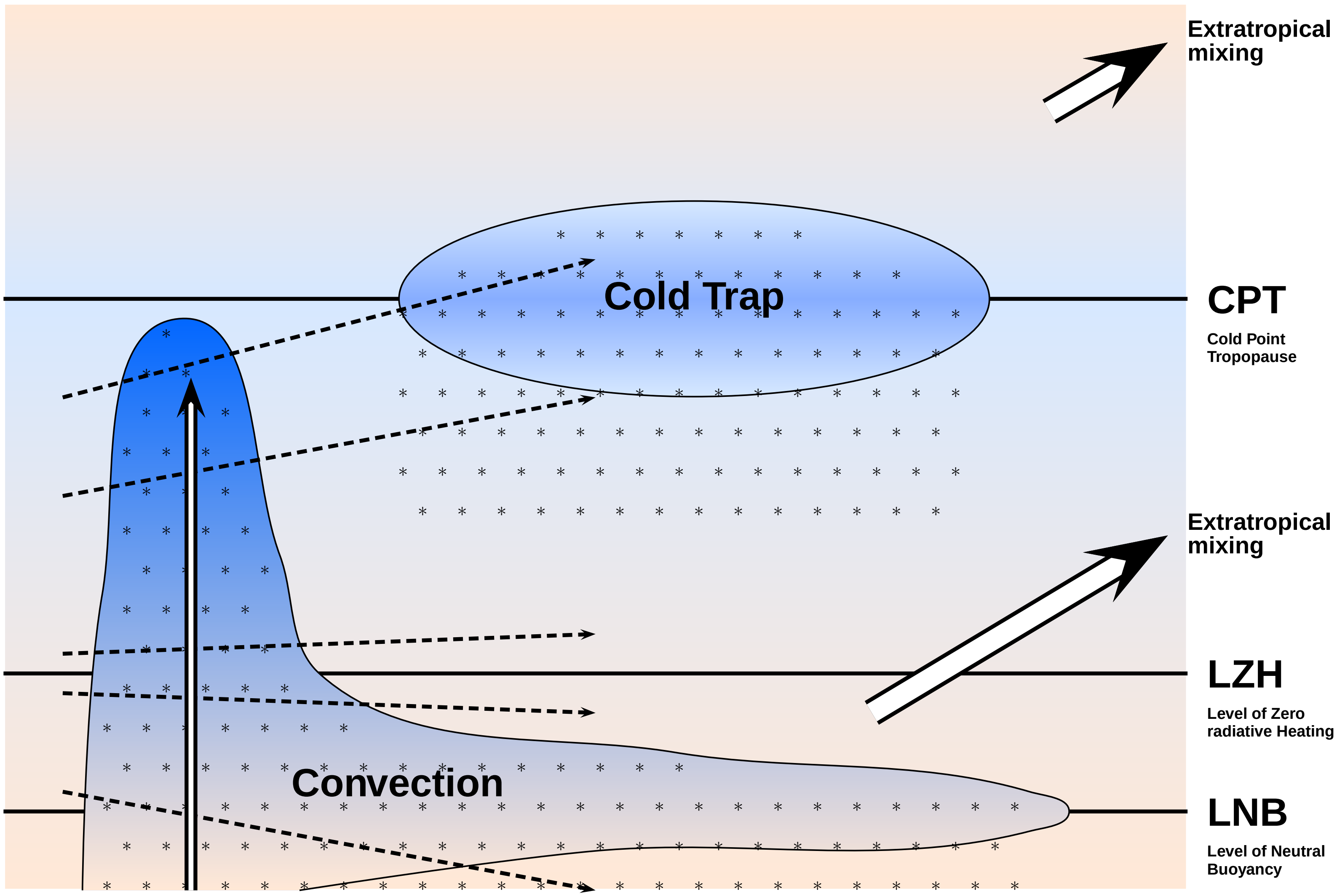
August–September 2008

+ = clear sky, ∗ = convection, ● = layer cloud, ○ = thin layer, ◇ = unclassified

H_2O Time Latitude

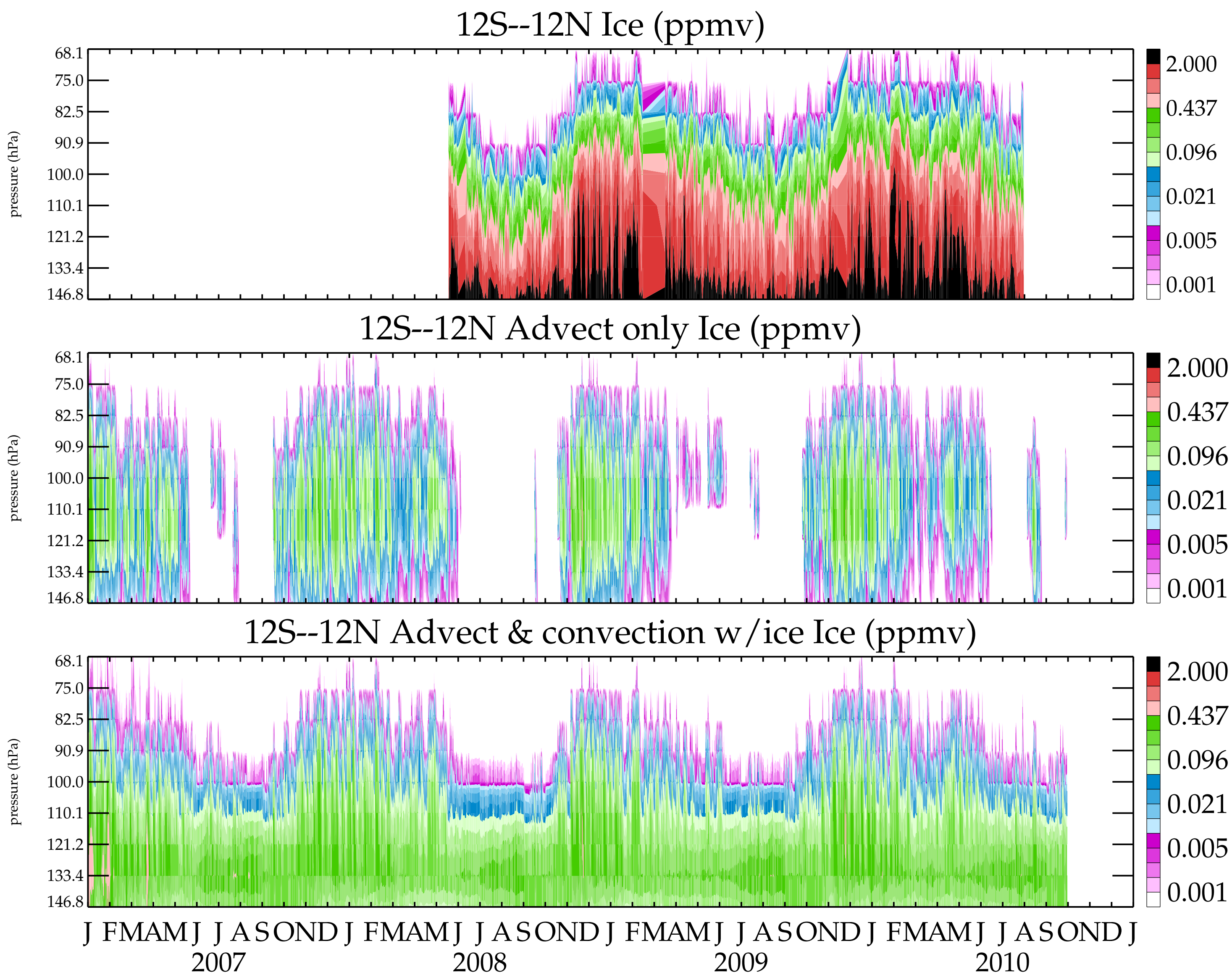


Conceptual TTL model

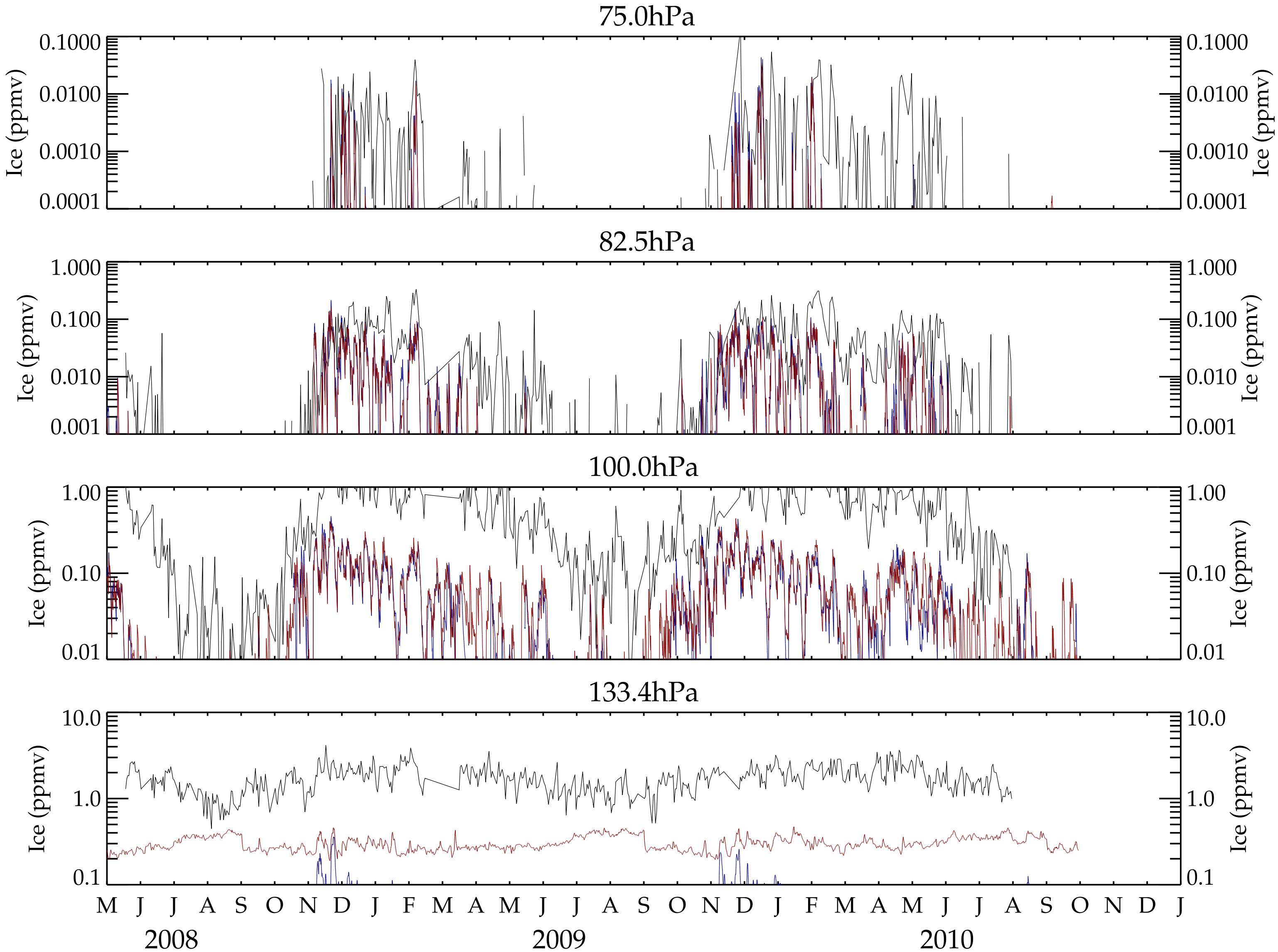


Model is driven with MLS temperature measurements with bias correction (Schwartz et al., JGR, 2008) and vertical velocities calculated from Yang et al. (JGR 2010) heating rates.

CALIOP and model IWC time series



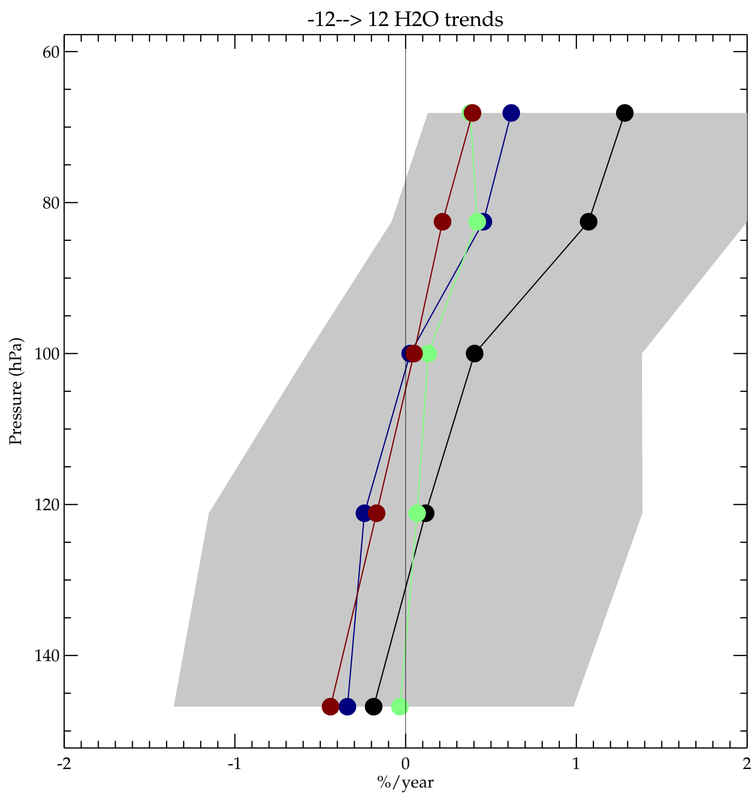
CALIOP and model IWC time series



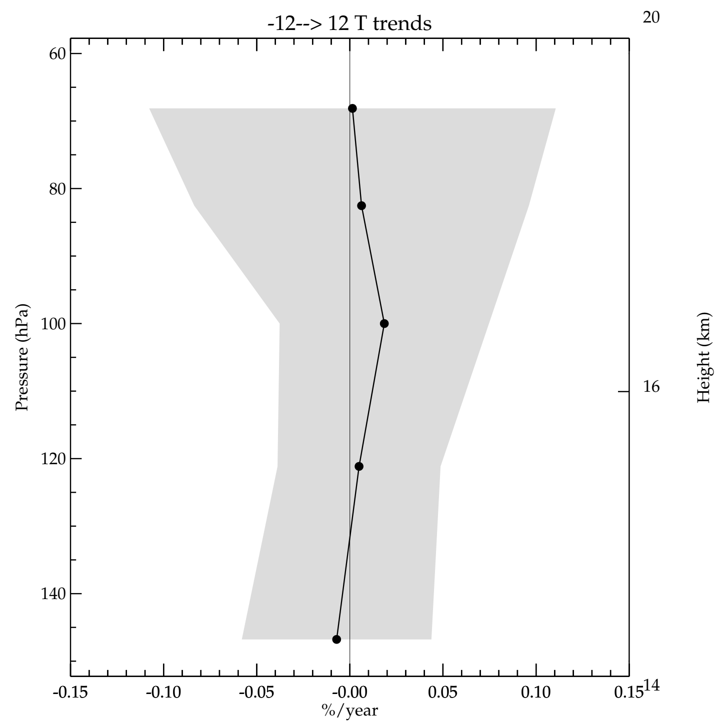
black: CALIOP v3.01 IWC, model run: no convection, model run: convection

H_2O & Temperature trends

H_2O



Temperature



- **Model runs (no convection, convection, convection vertical velocity from GEOS-5.2, MLS) show weak trends with a posituve slope in altitude. Same slope is also seen in MLS H_2O but is larger.**
- **The model trend is consistent with the temperature trend used to drive the model.**
- **I don't know why the trend shows a slope with altitude above the cold point tropopause.**

Summary

- A large annual cycle in IWC observed in the tropics at the tropopause.
- Convective clouds at 100 hPa also show a large annual cycle.
- Northern Hemisphere monsoons appear to transport humid air into the tropics.

Cold Phase Dec Jan

- Convection has significant detrainment above the level of zero radiative heating (LZH ~120 hPa) and cools the air.
- Layered clouds also exist in air that is colder than that in the H_2O binned average.
- In situ freeze drying occurs in this colder air.
- Upwelling mass flux which is larger at this time of year is balanced by more vigorous convective mass flux detrainment above the LZH.

Warm Phase Aug Sep

- Very little convective detrainment above the LZH. There is cooling of the air in convective clouds.
- Layered clouds also exist in air that is colder than that in the H_2O binned average.
- Data suggests that there is significant transport of moist monsoon air from the northern extratropics into the tropics. Some of this air may be freeze dried.
- Upwelling mass flux is lower at this time of year and is more closely balanced by mass influx from the extratropics. There is little mass flux from convective detrainment above the LZH.